# Gujarat University

# M.Sc. (Physics) Sem.-II

## Phy-410: (Analog Electronics)

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# Unit-I : Power Supply and Regulators

## The Operational Amplifier and Regulators

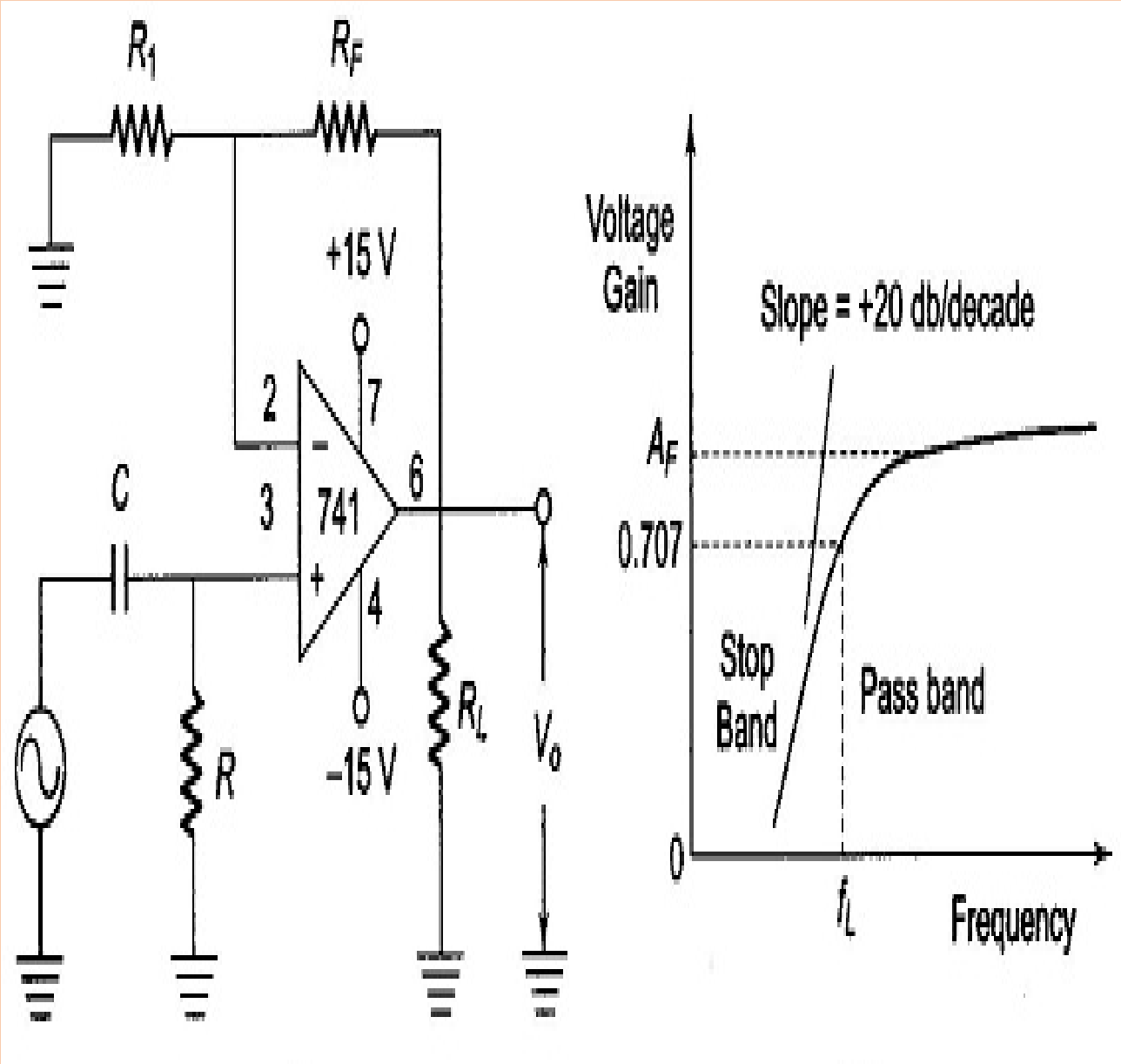
The Operational Amplifier & Applications : active filters, low pass, **high pass**, **band pass**, band reject, notch, first and second order filters, comparators, sample and hold circuits, Logarithmic & antilogarithmic amplifiers.

# Reference Books

- Integrated circuits, K. R. Botkar, Khanna Publishers.
- Electronic Devices and Circuit Theory, Robert Boylested and Louis Nashelsky, PHI. (Third edition).
- Electronic Fundamentals and Applications: Integrated and Discrete Systems, John D. Ryder, PHI, Fifth edition.
- OPAMP & Linear Integrated Circuits, Ramakant Gayakwad, PHI.

# First Order High-Pass Butterworth Filter

- It is simply formed by interchanging the frequency dependent resistors and capacitors in low-pass filter.
- Therefore, first order high-pass filter is formed from a first order low-pass type by interchanging components R and C.
- Similarly second order high pass filter is obtained from second order low pass filter if R and C are interchanged and so on.




- Here, Figure shows first order high-pass Butterworth filter with a low frequency $f_L$ at which the magnitude of the gain is 0.707 times its passband value.
- It is obvious that, all frequencies higher than the $f_L$ are passband frequencies with the highest frequency determined by the closed loop bandwidth of the OPAMP.

- The O/P voltage of such filter is

$$v_o = \left(1 + \frac{R_f}{R_1}\right) \frac{j2\pi f RC\, v_{in}}{1 + j2\pi f RC}. \qquad (1)$$

Or $$\frac{v_{out}}{v_{in}} = A_F \left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right]. \qquad (2)$$

one can write followings

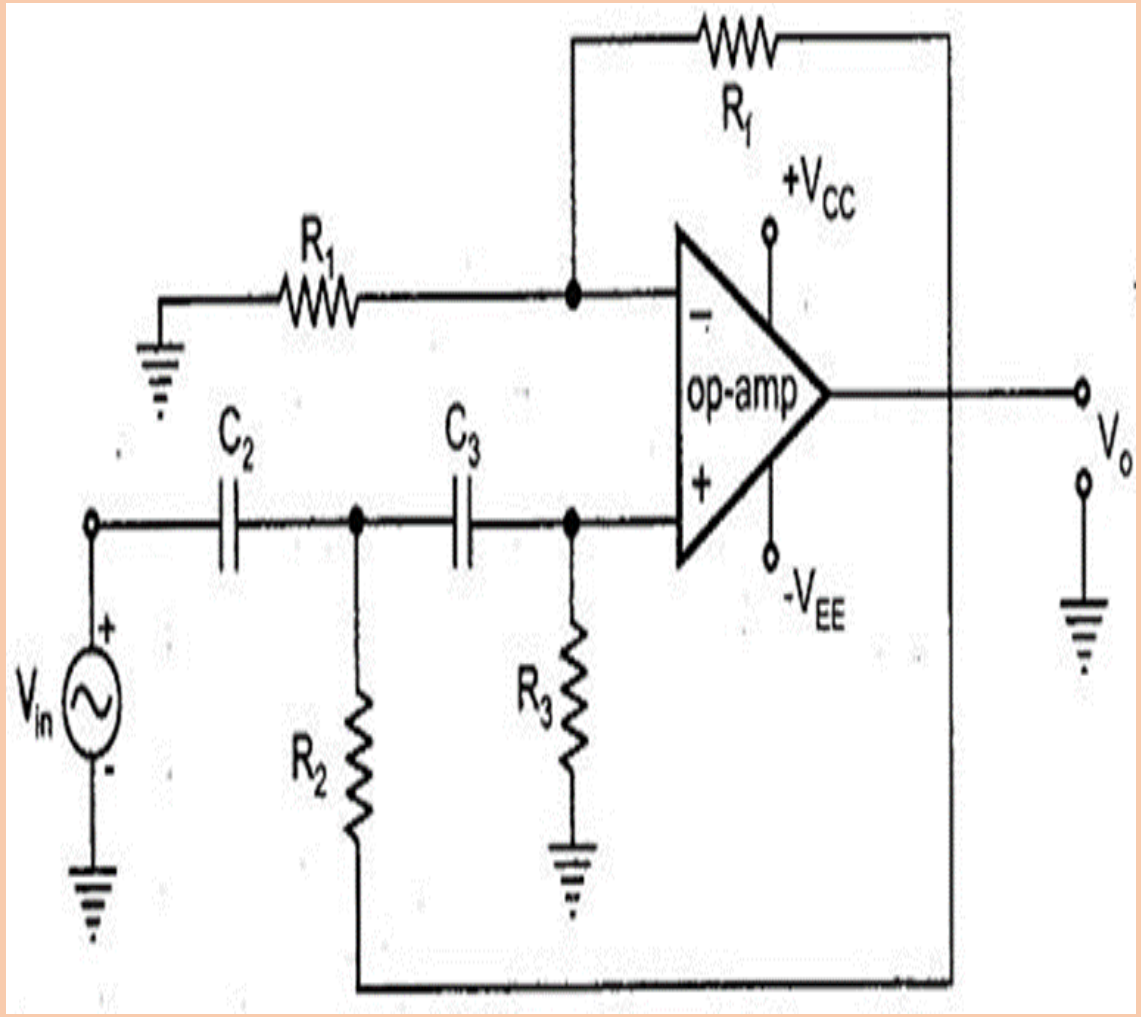
- $\frac{v_{out}}{v_{in}}$ = gain of the filter as a function of frequency,
- $A_F = \left(1 + \frac{R_f}{R_1}\right)$=passband gain of the filter,
- $f$ = frequency of the input signal (Hz), and
- $f_L = \frac{1}{2\pi RC}$ = low cutoff frequency of the filter (Hz).

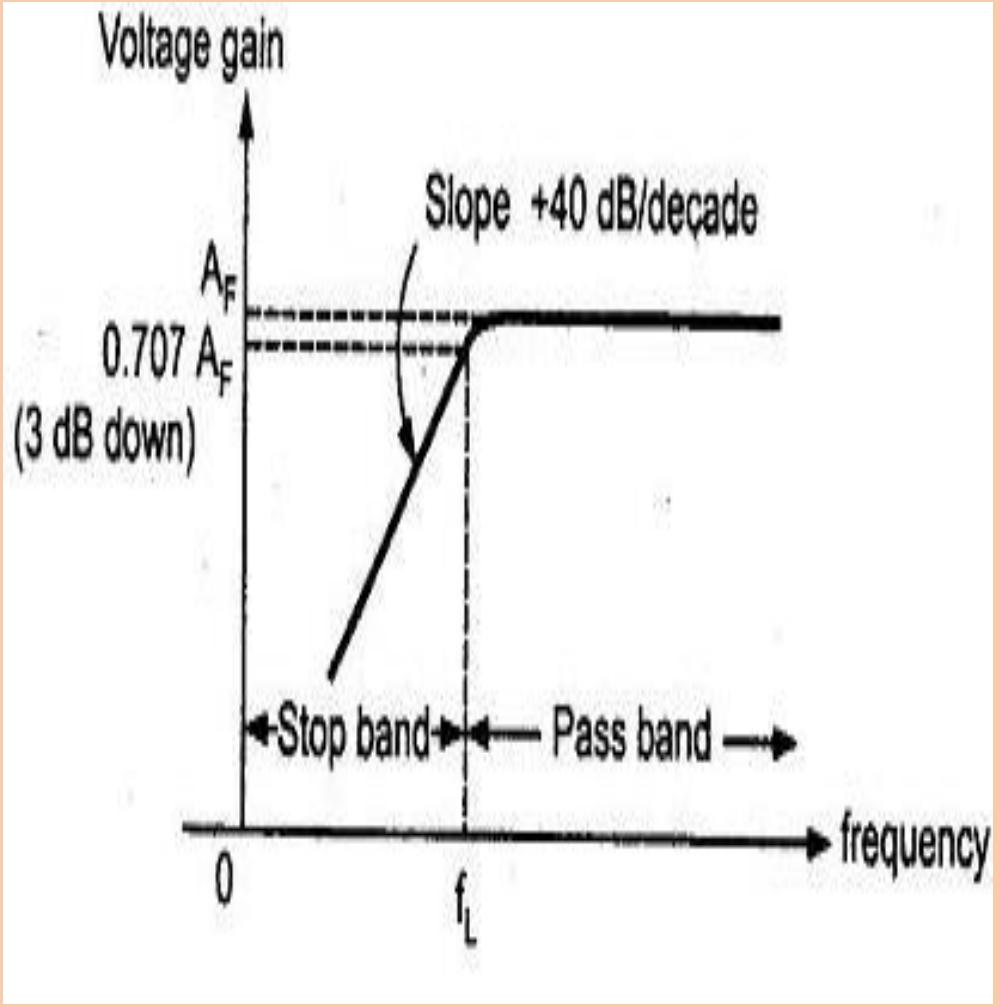
- Therefore, the magnitude of the voltage gain is

$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{A_F\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}. \qquad (3)$$

Since such filter is designed from the first order low pass filter by interchanging the R and C components, hence the designing procedure and frequency scaling of such filter are the same.

# Second Order High-Pass Butterworth Filter



- By interchanging the R and C components in second order low pass filter circuit, such filter is designed.
- Hence, the voltage gain magnitude equation of such filter is given by

$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_L}\right)^4}}. \qquad (3)$$

Where,

- $A_F = 1.586$ = passband gain for the second-order Butterworth response,
- $f$ = frequency of the input signal (Hz), and
- $f_L = \frac{1}{2\pi RC}$ = low cutoff frequency of the filter (Hz).

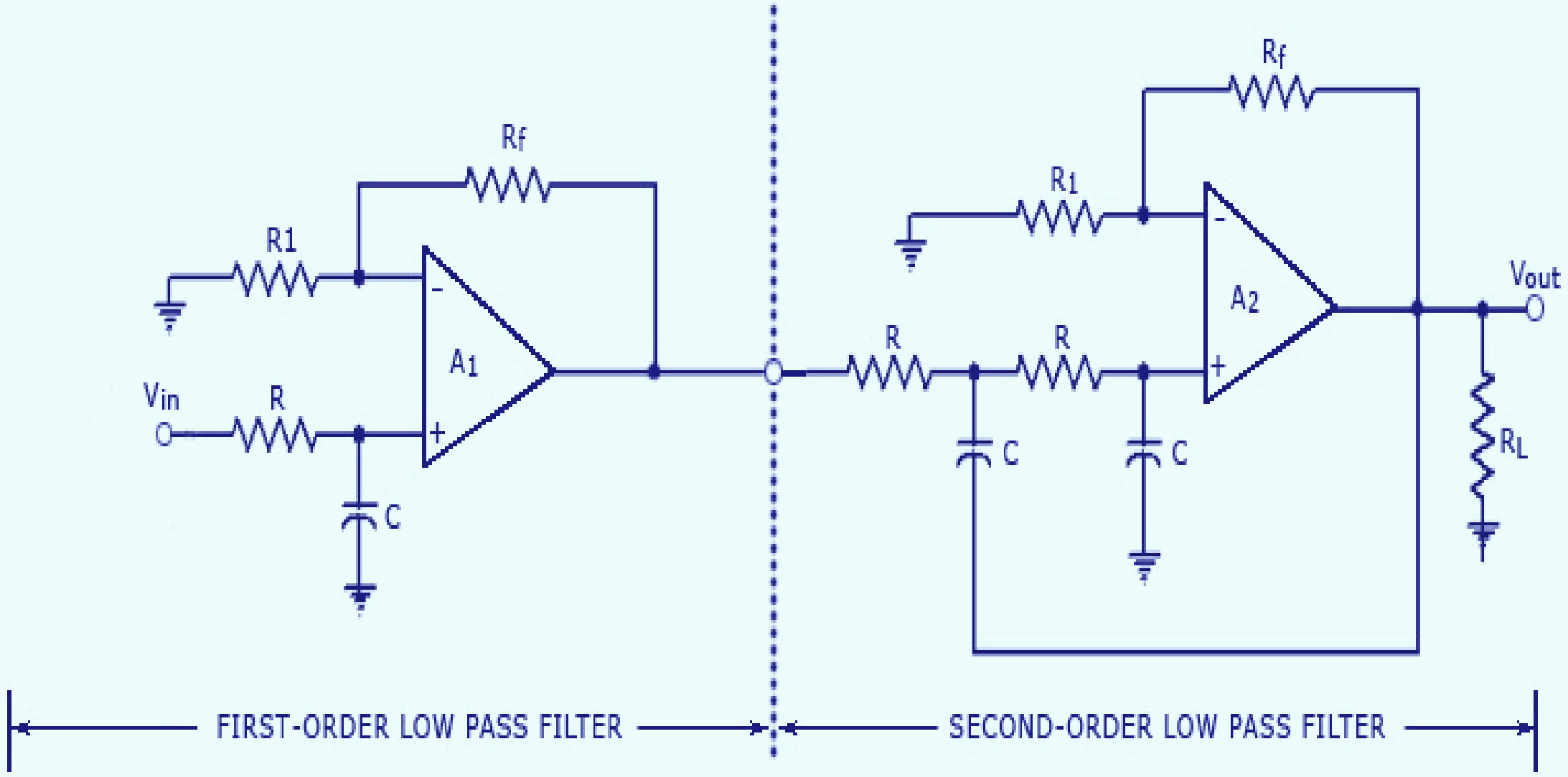
From the discussion made so far on the filters, it may be concluded that in the stopband gain of the filter changes at the rate of 20 db/decade for first-order filters and 40 db/decade for second-order filters. This means that as the order of the filter is increased, the actual stopband response of the filter approaches its ideal stopband characteristics. In general, a third-order filter produces 60 db/decade, a fourth-order filter produces 80 db/decade and so on.

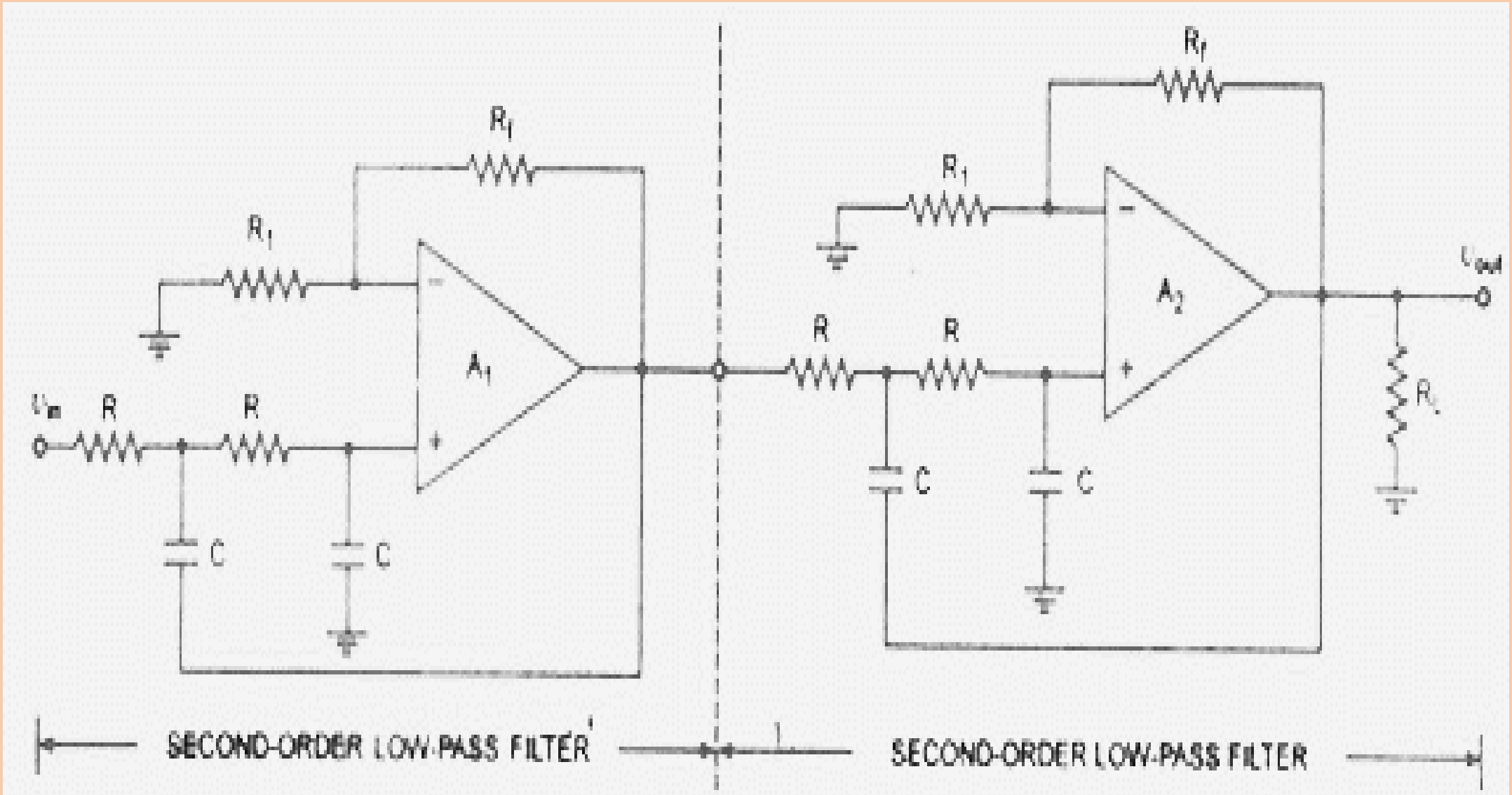
Therefore,

**Higher-order filters, such as third, fourth, fifth, and so on, are built simply by using the first and second-order filters.**

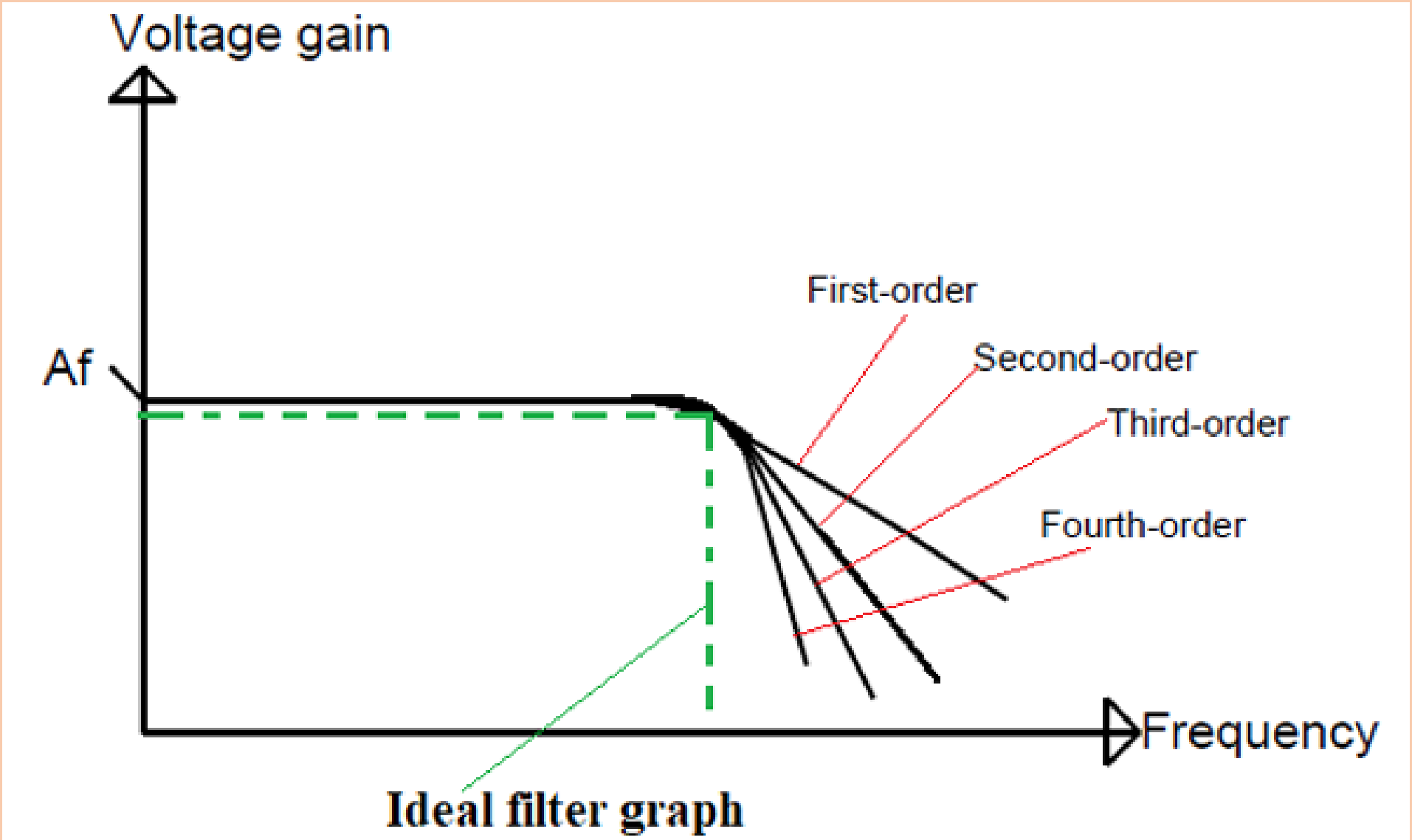
- The simplest way to build a third-order low-pass filter is by cascading a first order filter with a second-order.
- Similarly a fourth-order low-pass filter can be formed by cascading two second-order low-pass filters.
- Although there is no limit to the order of the filter that can be formed, as the order of the filter increases, so does its size.
- Also the accuracy declines, in that the difference between the actual stopband response and the theoretical stopband response increases with an increase in the order of the filter.

# Third- Order Low pass Butterworth Filter Circuit






*Fourth-Order Low-Pass Butterworth Low-Pass Filter*


Voltage gain
Af
First-order
Second-order
Third-order
Fourth-order
Frequency
Ideal filter graph

- In the 3rd order filter, the voltage gain of the 1st order section is *one* and that of the 2nd order filter section is *two*. Hence the gain of such filter is (2)x(1)=2.
- Similarly, in the 4th order filter, the gain of the first section is 1.152 and of the second section is 2.235. Therefore, the gain of the such filter is (1.152)x(2.235)=2.57.
- Such values are necessary to guarantee Butterworth response and must remain the same regardless of the filter's cutoff frequency.
- Since, frequency dependent R and C are also equal, the high cutoff frequencies of the higher order filters must also be equal i.e.

$$f_H = \frac{1}{2\pi RC}$$

- Similar procedure is adopted for designing higher order high-pass Butterworth filter.

# Band Pass Filters

- A band pass filter has a passband between two cutoff frequencies $f_H$ and $f_L$. Also $f_H > f_L$. Any O/P frequency outside passband is attenuated.
- There are two types of such filters :
  1. Wide bandpass, and
  2. Narrow bandpass.

There is no set dividing line between the two.

- However, we will define a wide bandpass filter if its figure of marit or quality factor Q<10.
- On the other hand, if Q>10, the filter is known as a narrow bandpass filter.

- Thus, Q is a measure of selectivity i.e. the higher value of Q, the more selective is the filter or the narrow bandwidth (BW). The relationship between Q, the 3dB bandwidth and the centre frequency ($f_C$) is

$$\mathrm{Q} = \frac{f_C}{f_H - f_L}$$

For the wide bandpass filter the centre frequency ($f_C$) is defined as

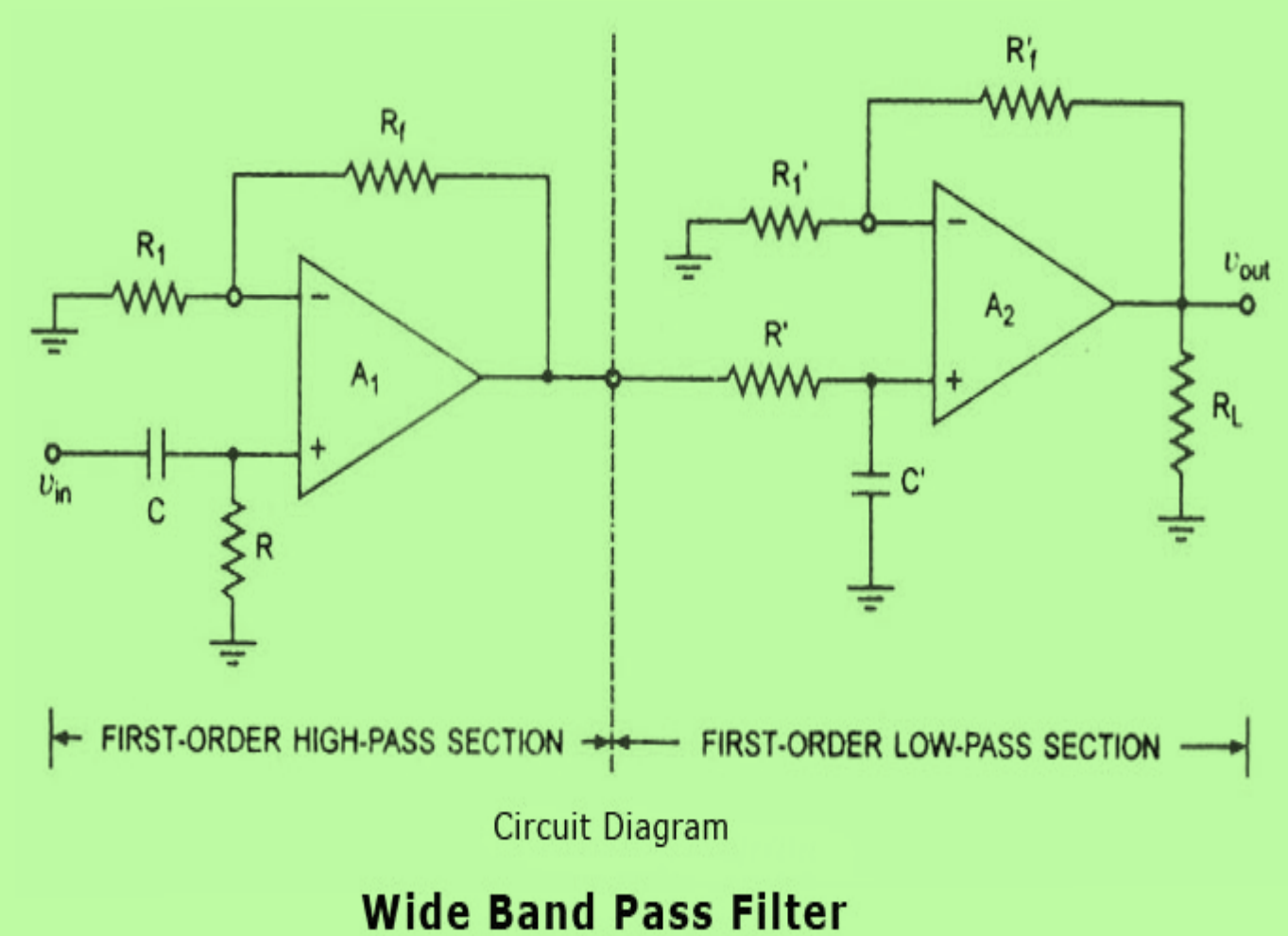
$$f_C = \sqrt{f_H f_L}$$

Where, $f_H$ = high cutoff frequency (Hz)

$f_L$ = low cutoff frequency (Hz)

- In a narrow bandpass filter, the O/P voltage peaks at the centre frequency.

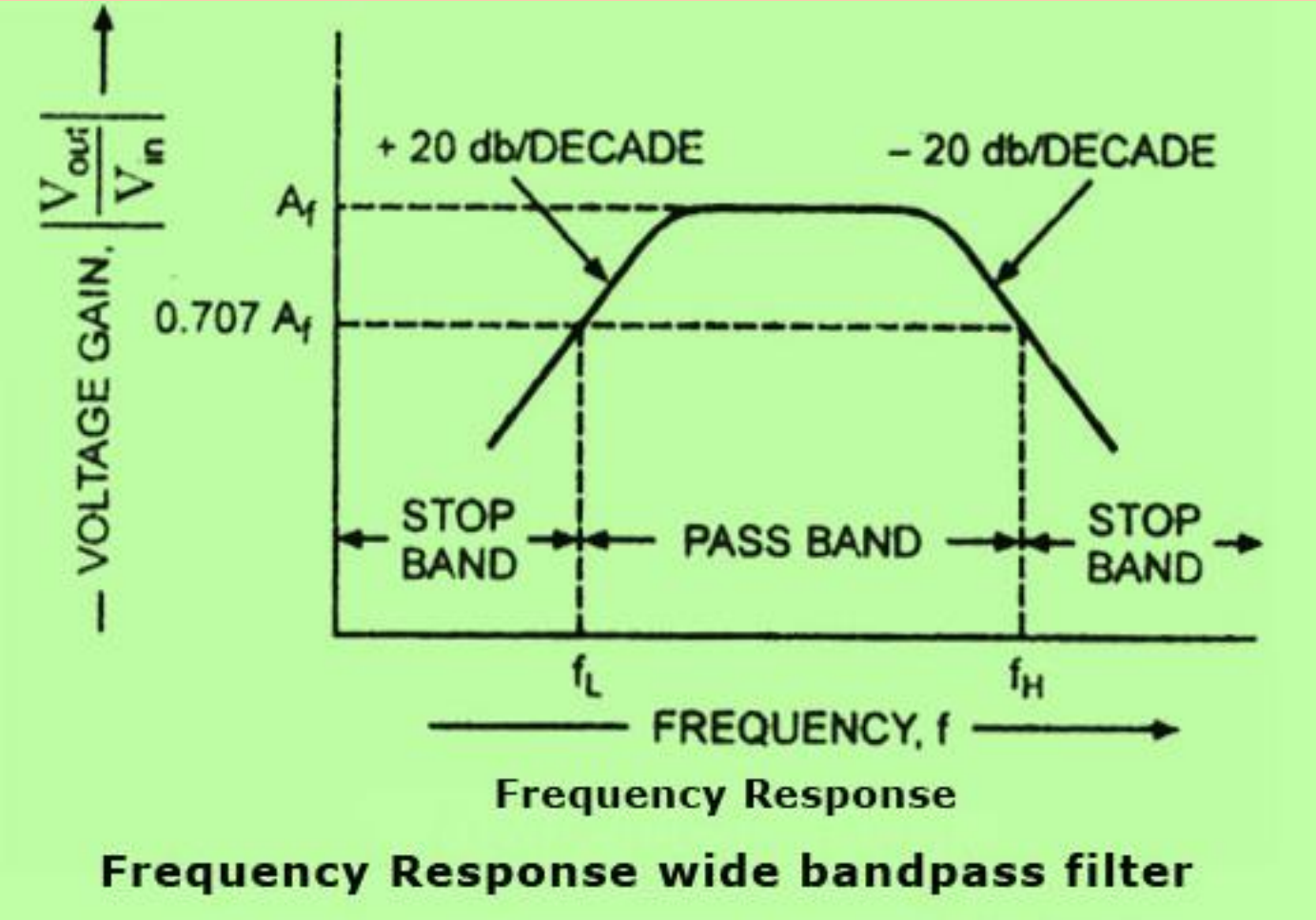
# Wide Band-Pass Filter




Circuit Diagram

**Wide Band Pass Filter**

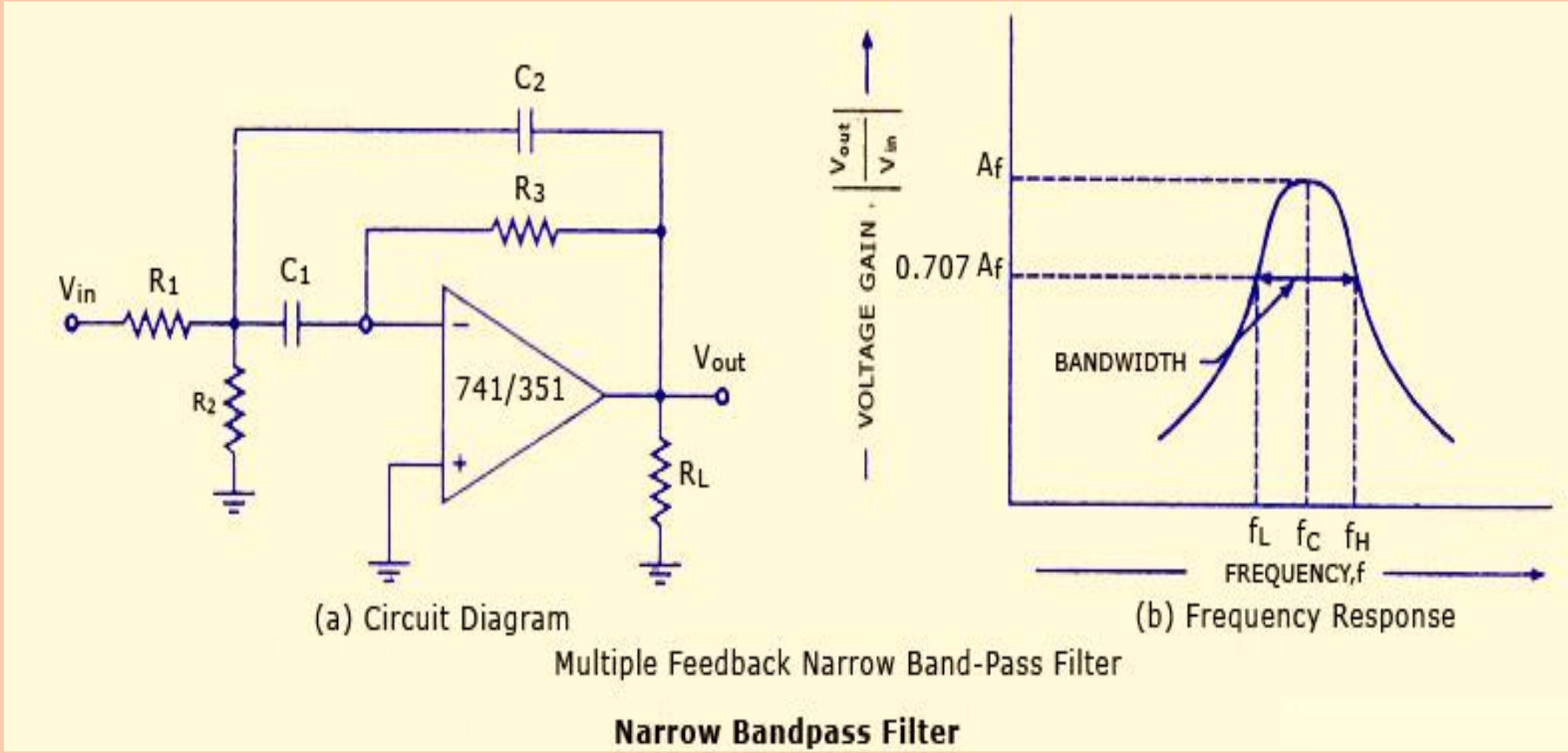
- A wide band-pass filter is formed by simply connecting the high pass and low pass sections and is generally the choice for simplicity of design and performance.
- To obtain a ±20 dB/decade band pass, 1st order high pass and 1st order low pass sections are cascaded.
- For a ±40 dB/decade band pass filter, 2nd order high pass and 2nd order low pass sections are connected in series, and so on.
- This figure shows the ±20 dB/decade wide band pass filter, which is composed of 1st order high pass and 1st order low pass filters.




**Frequency Response wide bandpass filter**

- Here, $f_H$ must be larger than $f_L$.

# Narrow Band-Pass Filter




Multiple Feedback Narrow Band-Pass Filter

**Narrow Bandpass Filter**

- This filter is using multiple feedback is shown in figure. Such filter is used only one OPAMP.
- It is an unique one then the other filters from the followings:
  1. It has two feedback paths, hence it is also known as multiple feedback filter.
  2. The OPAMP is used in the inverting mode.
- Generally, such filter is designed for a specific values of center frequency $f_C$ and Q or $f_C$ and bandwidth.

The circuit components are determined from the following relationships.

- Choose $C_1 = C_2 = C$.
- $R_1 = \frac{Q}{2\pi f_C C A_F}$ and $R_2 = \frac{Q}{2\pi f_C C(2Q^2 - A_F)}$ and $R_3 = \frac{Q}{\pi f_C C}$
- With $A_F = \frac{R_3}{2R_1}$
- Here the gain $A_F$ must be satisfied the following conditions: $A_F < 2Q^2$.

Another advantage of the multiple feedback filter is that, its center frequency $f_C$ can be changed to a new frequency $f_C'$ without changing the gain or bandwidth. This is accomplished simply by changing $R_2$ to $R'_2$ so that

$$R_2' = R_2\left(\frac{f_C}{f_C'}\right)$$

# Thank you